

SHOULD NON DEPARTMENT OF DEFENSE METEOROLOGICAL SATELLITES
BE USED TO MEET DEPARTMENT OF DEFENSE ENVIRONMENTAL
REQUIREMENTS?

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MASTER OF MILITARY ART AND SCIENCE
Military Space Applications

by

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the US Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

SHOULD NON DEPARTMENT OF DEFENSE METEOROLOGICAL SATELLITES BE USED TO MEET DEPARTMENT OF DEFENSE ENVIRONMENTAL REQUIREMENTS? by Major Christopher S Bjorkman, USAF, 60 pages.

This study investigated whether the Department of the Defense (DOD) policy should include civil, foreign, or commercial meteorological satellites to meet DOD objective environmental requirements. The study investigated if non DOD meteorological satellites can fulfill the DOD's need, United States (US) and DOD policy applicable to weather satellites, the cost savings of leveraging coalition assets vice commercial or additional US assets, and the risks of using non DOD assets to meet operational objectives.

The study identified the basic DOD requirements for environmental data, available civil, foreign, and commercial meteorological satellites, along with their capabilities and limitations to meet the requirements, US and DOD policy, and the available international agreements, which impacts the risks of using foreign assets. DOD requirements are broken into spatial and temporal resolutions and threshold and objective requirements.

In determining the optimal solution, the study identified alternate solutions, including foreign, commercial, or additional US assets, which could be used for DOD needs. The study discussed the alternative's capabilities and limitations along with cost considerations of utilization. The study concludes that DOD policy should include civil, foreign, and commercial meteorological satellites to meet objective requirements and requires a system of METSAT systems, which delivers a constellation of polar-orbiting and geostationary METSATs designed as a space architecture.

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ACRONYMS

USA	United States Army
DOD	Department of Defense
METSAT	Meteorological Satellites
USAF	United States Air Force
AF/XOW	Headquarters Air Force Directorate of Weather
DMSF	Defense Meteorological Satellite Program
USN	United States Navy
NRO	National Reconnaissance Office
SAC	Strategic Air Command
COE	Contemporary Operational Environment
NPOESS	National Polar-Orbiting Environmental Satellite System
DOC	Department of Commerce
NOAA	National Oceanographic and Atmospheric Administration
NPOESS	National Polar-Orbiting Environmental Satellite System
GOES	Geostationary Orbiting Environmental Satellite
GOMS	Geostationary Orbiting Meteorological Satellite
GMS	Geostationary Meteorological Satellite
INSAT	Indian Satellite
LEO	Low Earth-Orbiting Satellite
POES	Polar-Orbiting Environmental Satellite
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
METop	Meteorological Operational environmental satellite

MSG	Meteosat Second Generation
In-Situ	Direct Precise Measurement Of Weather Conditions
R&D	Research And Development
NASA	National Atmospheric and Oceanographic Administration
MJCS 154-86	Memo from the Joint Chiefs of Staff 154-86
IORD	Integrated Operational Requirements Document
PDD	Presidential Decision Directive
NSTC	National Science and Technology Council
MOA	Memorandums of Agreements

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CHAPTER 1

INTRODUCTION

“Know the ground, know the weather, your victory will then be total.”¹ Sun Tzu recognized nearly 2,500 years ago that a war fighter could gain an advantage by being aware of weather conditions and by understanding how these conditions affect the terrain and the enemy. Conversely, he realized the risks and disadvantages of not being aware of weather conditions and of failing to consider the effects on both friendly and enemy forces. His wisdom proved to be timeless, despite the technological improvements that mitigated some adverse weather effects on weapons and soldiers. Examples of how weather conditions led to military success and failures are scattered throughout the historical accounts of battles, campaigns, and wars, and so, too, are examples of how military commanders exploited or neglected information concerning the weather.

Perhaps two of the better-known illustrations of how weather and weather information played decisive roles in United States military operations are taken from the successful D-day invasion of Normandy during 1944 and from the failed American embassy hostage rescue operation in Iran during 1980. Exploiting the combined capabilities of the Army Air Force’s Weather Service and the British meteorological service, General Dwight D. Eisenhower relied on weather forecasts in selecting the optimal time to launch the Normandy invasion. Nearly two months before the operation, he told his senior staff and the air, ground, and naval commanders-in-chief, “As you all know, when the time comes to start Overlord we are going to have to rely very much on the weather forecast.”² True to his word, he obtained frequent weather updates and

successfully chose a time that provided the most favorable sea wave, wind, and cloud cover conditions during a period of otherwise very poor weather. More importantly, the Allied action during this period used weather forecasts to surprise the Axis due to weather exploitation, since Axis forecasters expected adverse weather to continue.

Thirty-six years later, during the Eagle Claw operation, a lack of knowledge and perhaps concern for desert sandstorms and suspended dust in Iran caused the hostage rescue mission to fail.³ Seven RH-53D helicopters were unable to reach their objective on time due to reduced visibility caused by blowing sand and suspended dust. Air Force and Navy meteorological personnel, specifically designated by their respective service's weather organizations to support the rescue operation, were not allowed to interface directly with the aircrew members prior to the mission. Such an indifferent policy as to how weather information was integrated into the planning and execution cycle of operations suggests that senior commanders did not consider weather to be an important factor and/or dismissed any potential weather impacts.

More recent examples of how weather and weather information played prominent roles in United States military operations include Urgent Fury in Grenada⁴, Just Cause in Panama⁵, Desert Storm in Iraq⁶, Joint Endeavor in Bosnia⁷, and Enduring Freedom in Afghanistan. Therefore, with respect to considering meteorological conditions and their effects, United States combat operations sometimes were conducted in accordance with the principles of Sun Tzu and the practices of General Eisenhower. At other times combat operations were conducted with apathy consistent with the sentiment described by General Phillip Sheridan, Commanding General of the Army, who testified to congress in 1886, "But what does a soldier care about weather? Whether good or bad, he must take it

as it comes.’’⁸ The answer to General Sheridan’s rhetorical question is that it depends on the specific military operation and on the particular systems being used by the soldiers.

While the types of weapons and other systems used in military operations have evolved over time, so, too, have the types of adverse impacts to military operations. Moreover, the number of meteorological elements affecting military operations during the last two centuries increased as technology improved. Prior to the nineteenth century, armies were concerned primarily with temperature, rain, and snow because of their adverse affects on soldier exposure, trafficability, maneuverability, and visibility. As the range of artillery and other weapon projectiles increased during the nineteenth century, the importance of wind conditions increased. With the advent of air operations in the early twentieth century, cloud conditions became relevant. And as sophisticated battlefield sensors and target acquisition systems were born in the mid to late twentieth century, subtler weather elements, such as humidity and slant-range visibility, took on a new importance.

As the United States Army (USA), together with the entire Department of Defense (DOD), accelerates the use of precision engagement systems to conduct command, control, weapons delivery, surveillance, reconnaissance, and other operations, the ability to identify impacts from weather is increasing. In turn, the ability to forecast mission impacts due to weather requires the ability to observe critical weather parameters worldwide in a near continuous manner.

To meet the requirement to gather observations, meteorological satellites (METSATs) with increased capabilities have been deployed. A critical METSATs advantage over ground observations is that METSAT coverage includes the 70 percent of

the earth covered by water where few surface observations occur. Before the deployment of METSATS, many areas had no observations and weather impacts to military operations couldn't be analyzed, forecasted, or assessed.

Problem and Fundamental Question

This study proposed to investigate whether policy should include the use of non DOD METSATS, to include civil, foreign, or commercial capabilities in meeting DOD objective environmental requirements. The research investigated: (1) current requirements and the DOD's ability to meet them with organic assets, (2) civil, foreign, and commercial METSAT capability for fulfilling DOD's need for weather data, (3) national and DOD space policy, (4) impacts and the potential risks of using non-military assets, and finally, (5) the cost considerations of using non DOD assets to meet information operation objectives.

In regard to the DOD's possible use of civil, foreign, or commercial METSAT systems to meet operational requirements, the United States Air Force (USAF) Directorate of Weather (AF/XOW) noted there was a lack of a definitive policy on this matter in the spring of 2002. Accordingly, the research focused on the belief it was appropriate to develop a position, which could be used by the Air Staff and Joint Staff. The ultimate goal was to gather research and propose a position for policy.

In short, the proposal focused on developing research to support an argument for or against an overall policy and would propose a position on the use of non-DOD meteorological satellites to meet DOD environmental requirements. Initial staff work performed by AF/XOW in 2002 indicated the use of civil, foreign, or commercial

METSATs would be linked to potentially to two levels of requirement support: (1) threshold requirements or the minimum capability required and (2) objective requirements or desired or unconstrained capability to meet environmental sensing needs. To meet core threshold requirements, AF/XOW assumed the US military would continue to rely on US polar-orbiting METSAT systems. This approach would provide the DOD with a minimum capability to minimize risk. However, the evolving abilities of precision guided munitions and their vulnerability to impacts from weather require a better ability to observe current worldwide weather conditions to determine those impacts. Therefore, AF/XOW assumed the US military would build on our core polar-orbiting systems and partner with our allies and other nations to provide maximum benefit. Further, it was determined that the DOD required assured access and the capability to deny our adversaries critical data, an idea consistent with the initial DOD feedback on the subject. This approach would provide an ability to improve capability, recognizing the objective requirements of the Combatant Commanders. However, AF/XOW could not identify a source study, which assessed core METSAT capabilities, identified options, and proposed recommended solutions. This thesis attempts to produce such a study. Therefore, the purpose of the research was focused on: (1) a potential optimal solution, which provided the greatest benefit for requirements from available capabilities, (2) investigated national space policy, (3) minimized the threat or risk of interrupted data, and (4) optimized the cost-benefit considerations of potential solutions.

For thoroughness, the thesis investigated where solutions could be obtained from systems operated by the civilian agencies, foreign governments, or commercial vendors. The motivation for the development of a DOD policy was a proposal by the Office of the

Oceanographer of the Navy to move a US civil geostationary METSAT over the Indian Ocean and received visibility at the highest levels of US military leadership as well as within the US government in 2002. The US and Japanese governments agreed to reposition a US geostationary METSAT over the central Pacific ocean to provide a temporary measure until the Japanese successfully launched a replacement to their failing geostationary METSAT. The key component to the US decision to reposition a \$250 million Department of Commerce (DOC) satellite was a triservice memo from the DOD, which emphasized DOD requirements for continuous weather data in the region.⁹ In addressing the requirement for weather data in the Pacific due to the failure, the DOD acknowledged an increased need for data obtained from geostationary METSATS.

The Navy estimated the proposal to move the additional US system to the Indian Ocean vice the western pacific would cost \$18 million for ground processing capabilities, along with the \$250 million cost for the satellite itself. The area ground coverage from such a move would produce redundant coverage and capabilities already provided by an existing European civil geostationary METSAT system (METEOSAT-5) and the system met DOD requirements and provided adequate area coverage. Therefore, the additional US system would produce a questionable added benefit to DOD operations at a significant cost to the nation. Further, the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) routinely provides data from their existing METSATS to the US government without charge, per standing agreements.

While US and allied geostationary METSAT systems are primarily for civilian use, the DOD historically used these civilian systems to augment DOD polar-orbiting systems. Therefore, the AF/XOW, representing user requirements of the USAF and USA,

dissented with the Navy position that DOD should fund and operate a redundant US geostationary meteorological satellite system. The different positions of the services led to an ambiguous position. This thesis could lead to a more definitive position and policy that resolves this issue and plots a course for the METSAT cooperation with our allies.

Therefore, the thesis intended to: (1) identify the basic DOD requirements for space-based remote sensing of environmental data, (2) evaluate the current ability of the DOD METSATs to meet these requirements and determine any capability shortfalls with the root cause, (3) investigate the available civil, foreign, and commercial METSATs, along with their capabilities, limitations, and reliability to meet the requirements, (4) research the national and DOD policy, which allow US and foreign METSAT collaboration, (5) assess the risks of using foreign assets, and (6) identify the cost considerations of using non-DOD METSATs to meet DOD requirements. Since the thesis conclusion was built upon the DOD's requirement for weather data, the study evaluated DOD requirements and assessed the accuracy, as well as the spatial, radiometric, and spectral and temporal resolution of the data.

To determine the optimal solution, the study examined alternate options, including civil, foreign, and commercial assets, to build an architecture for DOD needs. The study discussed the METSAT's capabilities and limitations. In the end, the study intended to produce a conclusion either for or against supporting a policy, on the use of non-DOD METSATs to meet requirements. As mentioned earlier, no comprehensive study of the roles and relationships between civil, foreign, and commercial METSATs to meet DOD requirements existed. The question of how the DOD could officially use civil, foreign, and commercial weather satellites remained unanswered.

The relationship between DOD and non-military METSATs is an important consideration and is related to the military use of METSATs to support doctrine and missions. Historically, the role of the Defense Meteorological Satellite Program (DMSP) was to support the Intelligence Community and the concept of nuclear deterrence through USAF strategic bombing and United States Navy (USN) nuclear submarines.

In fact, DMSP was designed, developed, and procured by the National Reconnaissance Office (NRO) to support their operations and, in turn, support the strategic targeting at Strategic Air Command (SAC) for strategic, nuclear-operations, which was basic USAF airpower theory.¹⁰ Often this support was restricted to classified operations for the Central Intelligence Agency and other national institutions for strategic estimates by the National Command Authority. However, since the development of the Air Land Battle doctrine in 1986 and the emphasis in operational war fighting after the 1991 Gulf War, current US doctrine requires ubiquitous weather observations to support military operations in the Contemporary Operational Environment (COE). Without an understanding of the changes in doctrine, one could challenge the merit of this thesis, since many of the concepts discussed are common to some military officers.

Despite the weather community's understanding of the benefits of METSATs, a comprehensive DOD study justifying the inclusion of non-DOD METSATs, or an identification of the proper combination of METSATs in varying orbits to meet the DOD objective requirement for data refresh rate of fifteen minutes, addressed in the Memo from Joint Chiefs of Staff 154-86 (MJCS 154-86), does not exist. In fact, when the Air Staff coordinated the previously mentioned GMS-5 requirements memo, AF/XOW

recognized no document existed stating the DOD required METSATs besides DMSP and the National Polar-Orbiting Environmental Satellite System (NPOESS) constellations. While on the surface this may appear perplexing, prior to the 1990s there was no reason for this type of study to exist. Since the advent of METSATs in the 1960s until approximately after the Gulf War, the predominant theory of the Air Force was strategic bombing. It follows that the funding justification for DMSP for thirty years was AF Precedence 1-1, support to the then classified NRO. Based solely on this justification, the DOD fought successfully for a separate DOD METSAT until the 1994 Presidential decision to merge the civil and DOD programs to create NPOESS. While METSATs can support operations at various levels, the military, and USAF in particular, did not emphasize operational and tactical operations with the same intensity as strategic operations until after the Gulf War and the emergence of new airpower theories and theater-level war. As the military weather community works to build a ubiquitous database for today's COE, which is timely, accurate, and relevant to Global Reach and Power, this thesis intends to provide a source document either to justify or argue against the inclusion of non-DOD METSATs. The thesis also intends to identify the proper combination of METSATs in varying orbits and proposed an architecture of system of METSAT systems to meet DOD mission requirements.

To determine if non-DOD METSATs should be included in policy to meet DOD requirements, several subordinate issues were analyzed. There were three phases to this thesis. The first phase included an analysis of all available resources appropriate to answering the question and the associated supporting questions. Additionally, the first phase identified the DOD requirements for space-based remote sensing of environmental

data and evaluated the current ability of the DOD METSATs to meet these requirements. The second phase identified the capabilities to observe weather using METSATs, investigated the capabilities and limitations of various space systems, and investigated the available civil, foreign, and commercial meteorological satellites to meet the requirements. The third phase researched the policy and available agreements, which allowed the use of commercial space assets, as well as US and foreign civil METSAT collaboration. Phase three also looked at national space policy, with an emphasis concerning METSATs and any potential risks to DOD operations, in order to analyze a balance of policy, risk, and cost of using non-DOD METSATs to meet requirements

In order to answer the questions within the time constraints for completing this thesis, five limitations existed. First, the thesis remained unclassified, thus excluding research efforts on many operations, such as the support to the Intelligence Community. Second, the thesis only addressed meteorological satellite systems that are either operational or scheduled to become operational before the year 2010. There are many potential METSATs intended for future operations, especially commercial systems, but it was difficult to analyze concepts. Third, the thesis limited discussing the science of weather observations using electromagnetic wavelengths and spectral analysis to the basics for an understanding of METSAT capabilities and limitations. Investigating the various sensing packages, which are available to be added to METSAT platforms, would be a tremendous undertaking. Therefore, the research concluded the science of the individual METSAT sensors were capable of meeting DOD requirements. However, some METSATs may not meet DOD needs because of a satellite's orbit, position, maintenance, or data flow reliability, not due to the individual sensors.

Next, the research relied largely on military and civilian personnel working on meteorological satellite programs and policy. I relied on these personnel to provide technical information and to describe concepts of operation. They provided informal policy guidance, which may not be available through traditional means, such as formal publications. Therefore, the thesis research may be, in part, steered by the expertise, biases, and opinions of personnel who may have an interest in the outcome of this paper.

Finally, the thesis evaluated all available METSATS but, due to the results of the investigation, focused the analysis on the contribution of the national meteorological satellites, such as the European and Japanese METSATS, due to the reliability of superior technological capabilities. While Chinese, Indian, and Russian METSATS exist, the technology is unreliable, the maintenance records poor, and the potential risk of continuous support during contingency or wartime operations is considerable.

In spite of these limitations, this study remains potentially significant to DOD operations and may prompt similar investigation of other US government operations. The results of this thesis may affect acquisition and policy within the DOD and US government. For example, the Joint Staff may include the use of non-DOD meteorological satellites in joint policy and the DOD may formally submit their requirements to the Departments of Commerce and State for fulfillment. In this case, the ultimate objective of the thesis would be to cause the US government to clarify agreements with foreign governments, like the European and Japanese METSATS programs, to ensure timely and reliable weather data for all levels of US military activity.

In addressing the requirement for weather data in the Pacific basin, the DOD acknowledged an increasing need for reliable, accurate, and continuous weather data

obtained from METSATs to support modern weapons. Advanced technology during the last two centuries yielded more sophisticated and capable weaponry, but technology did not eliminate the need for combat forces to deal with adverse weather impacts on soldiers or weapon system performance while trying to exploit those weather conditions more disadvantageously to the opponent. In some cases, new systems yielded greater sensitivity to weather impacts. In all cases, military forces required a space-based capability to monitor weather conditions. This thesis attempts to determine if non-DOD meteorological satellites should be used to meet the DOD's environmental requirements.

¹Sun Tzu, *The Art of War*, trans. Samuel B. Griffith (New York: Oxford University Press, 1963), 129.

²John F. Fuller, *Thor's Legions* (Boston: American Meteorological Society, 1990), 89.

³*Ibid.*, 387-390.

⁴⁴*Ibid.*, 392-395.

⁵Thomas Donnelly, Margaret Roth, and Caleb Baker, *Operation JUST CAUSE* (New York: Lexington Books, 1991), 201.

⁶Michael D. Gordon and General Bernard Trainor, *The General's War* (Boston: Little, Brown, and Company, 1995), 355, 390, 397.

⁷Tom Squitieri, "In Bosnia, Weather is Primary Foe", *USA Today*, (Roslyn, VA: USA Today: 29 December 1995, sec. A), 1.

⁸Fuller, 6.

⁹Christopher S. Bjorkman, *DOD Western Pacific Meteorological Satellite Requirements* (Washington DC: HAF Directorate of Weather, February 2002), 1.

¹⁰R. Cargill Hill, *NRO History: A History Of The Military Polar Orbiting Meteorological Satellite Program* (Washington, DC: NRO History Office, September 2001), 17.

CHAPTER 2

LITERATURE REVIEW

There were four general categories of research sources relevant to the question of determining if non-DOD meteorological satellites should be used to meet DOD weather requirements. The first source were those that identified the required abilities to observe weather parameters using remote sensing through meteorological satellites. The second type of literature concerned those sources that identified the various meteorological satellites and specified the capabilities and limitations of those various satellites. Next were the sources that describe the US military's expanding use of space and those, which discuss evolving space policy, reliability, security, and risk. The fourth literature research area available was the cost associated with the various satellite systems.

The first research sources were those that identified the required abilities to observe weather parameters using remote sensing through METSATs. The US began observing and forecasting weather in the 1900s and the requirements to observe weather parameters are quite refined. Further, the DOD used remote sensing through satellites to observe weather parameters in the early 1960s. The responsibility to document METSAT requirements belongs to the USAF. The task to collect observations from METSAT is responsibility of the AF to provide weather support to the Army and the Intelligence Community. These responsibilities are described in Air Force Doctrine Document 45, *Aerospace Weather Operations*,¹ AF Policy Document 15-1, *Atmospheric and Space Environmental Support*,² and Joint Publication 3-59, *Joint Doctrine for Meteorological and Oceanographic Support*.³

The most comprehensive document of the DOD's METSAT requirements is contained in the *National Polar Orbiting Operational Environmental Satellite System (NPOESS) Integrated Operational Requirements Document*.⁴ This paper thoroughly documents all requirements for NPOESS, which will be operational in the 2010-2020 time frame. NPOESS will provide global imagery and meteorological data for DOC requirements and DOD peacetime and wartime missions.

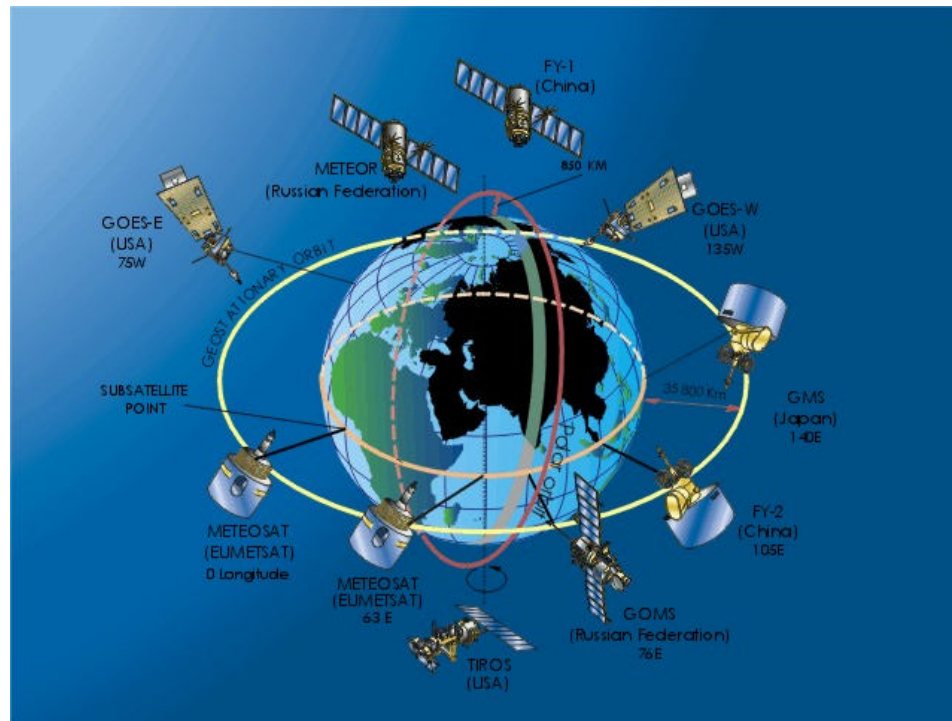
USAF's Phillips Lab, in *Global Weather Awareness*,⁵ explained the meteorological needs of the military but go well beyond the civilian requirements because of the DOD mission to execute operations on a global scale requires a worldwide weather observation network. To complicate matters, military areas of interest are often non-permissive, emphasizing remote sensing. Despite the differences, the need for global three-dimensional observations is common to both military and civilian meteorology; thus the Defense and Commerce Departments have many common requirements.

For a discussion of US civil weather needs, NOAA's National Environmental Satellite Data and Information Service discussed requirements in the report *Federal Agency Satellite Requirements*.⁶ This report summarized the requirements of Federal agencies for the data from civil operational environmental satellites--both polar-orbiting and geostationary. This document described current and planned use of the data from US METSATS, as well as those provided by the systems of others. Agency plans for taking advantage of proposed future METSATS, domestic and foreign, are cited also.

The second type of literature concerned those sources that specified the capabilities and limitations of the various meteorological satellites and represented the most significant portion of the research, see figure 1. The wide-ranging view from

satellites makes it possible to observe weather over a large area. METSATS can be found in two types of orbits: geostationary to give the regional big picture, and low earth orbiting (LEO), polar sun-synchronous to collect worldwide data closer to the earth. The advantages of using LEO satellites and high altitude geostationary orbiting satellites counterbalance the disadvantages of each type of orbit. Using satellites in both types of orbits, it is possible to observe 100 percent of Earth and provide the most accurate data available to merge with the ground weather data. The types of orbits used by METSATS and their contributions to resolution and accuracy of data are discussed more in chapter 4.

Figure 1 Commercial/Civil Weather Satellites.



There are sixty-eight different METSATS estimated to be operating as of October 2002. The DMSP and National Oceanographic and Atmospheric Administration (NOAA) satellites evolved from the first weather satellites. NOAA also operates the Geostationary Orbiting Environmental Satellites (GOES). Russia maintains Meteor weather satellites in low orbit and operates the Geostationary Orbiting Meteorological Satellite (GOMS). The European Meteorological Satellite Organization operates the METEOSAT satellites. Japan operates the Geostationary Meteorological Satellite (GMS) system. India operates the constellation of Indian Satellites (INSAT). China launched Feng Yun weather satellites. The broad categories of METSATS (polar orbiting satellites and geostationary satellites) and examples of each are briefly explained below.

The Low Earth, polar orbiting (polar or LEOs) satellites orbit much lower than the geostationary satellites. Because of this, they do not capture as much area at once. Polar METSATS provide world coverage and higher resolution imagery than geostationary satellites. Geostationary satellite images are distorted at the edges because of the low angle the satellite uses. Polar satellites also circle at a much lower altitude (about 530 mile, 850 kilometer) providing more detailed information. Only the US, Russia and China operate polar METSATS, where the satellite passes over the same point each day with regard to sun angle.

The US has two types of polar, LEO, sun-synchronous METSATS. DMSP provides weather data and disseminates global visible and infrared (IR) and other specialized data for DOD operations. The DMSP resolution is 0.5 kilometer with a swath width of about 2,800 kilometer. The NOAA Polar Orbiting Environment Satellites (POES) provide images, temperature, and moisture with a resolution of 1.5 kilometer.

The US is not the only country operating METSATs. Weather is important to all countries and several have satellites in either polar, geostationary or both types of orbits. The United Nations formed the World Meteorological Organization in 1951 to facilitate international cooperation of networks of meteorological observations and to exchange meteorological information.⁷

The Russian Meteor 1 program operates a single, integrated space-based network designed to meet all civilian, military, and governmental requirements. No encryption is used and the format is the same format as NOAA satellites. Most US weather satellite receivers can receive data from Meteor. The resolution is about 2 kilometer with a swath width of about 2,000 kilometer.⁸

The Feng Yun 1 is a Chinese weather satellite in a sun-synchronous polar orbit. The highest resolution is about 1 kilometer. Each image covers an area about 1,600 kilometer wide and 3,200 kilometer long. The formats are compatible with US satellites.

NPOESS, which begins operations in 2010, is a DOD, DOC, and NASA program and merges two systems, the POES and DMSP. In 1994, President Clinton approved the convergence of the two US polar orbiting systems. The on orbit architecture will consist of three satellites, which is a reduction from the current four satellites (two civilian and two military). The NPOESS resolution is 0.5 kilometer with a swath width of 2,800-kilometer.⁹

The European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), a consortium of seventeen European States, is preparing a European polar METSAT. The Meteorological Operational (METOP) satellite, which begins operations in 2009, will have a resolution of 1.0 kilometer and is complementary to NPOESS.

A second METSAT category is maintained in geostationary orbit for a continuous watch of the weather on the region below them. Each geostationary METSAT is able to continuously scan approximately one third of the Earth, however the effective range is about 20 percent of the earth. This position allows continuous monitoring of large, specific regions and provides the capability to meet DOD temporal requirements. A succession of satellite photographs can be displayed in sequence to produce a movie showing cloud movement. The US, Europe, Japan, and India operate geosynchronous METSATS.

The system operated by the US is GOES. There are no military geostationary METSATS. Geostationary METSATS provide half hourly observations, however they do not provide worldwide coverage because the METSATS cannot view the polar and high northern latitude regions. NOAA operates GOES, which provides weather data for the Western Hemisphere and particularly for the US. The resolution is 1.0 kilometer directly beneath the satellite, and resolution gradually decreases in accuracy as distance increases away from the satellite sub-point.¹⁰

Meteosat satellites are owned and operated by EUMETSAT. Meteosat sensors are similar to GOES. The Meteosat system provides observations from space every 30 minutes. EUMETSAT's system is intended primarily to support the Member States. Second priority is given to non-Member States in the continuing tradition of data exchange. Meteosat resolution is 2.5 kilometer directly beneath the satellite.¹¹ The Meteosat Second Generation (MSG) will be an enhanced follow-on system with improved resolution (1 kilometer as opposed to 2.5 kilometer on the current Meteosat).

India's INSAT series of geostationary spacecraft perform the dual missions of communications and meteorology. INSAT carries a visible sensor with 2-kilometer resolution and 8-kilometer resolution for the IR sensor. The sensors are similar to those on GOES.

The Geostationary Meteorological Satellite (GMS) program consists of a series of satellites operated by the Japan Meteorological Agency that images the western Pacific Basin. GMS provides visible and infrared images and weather observations. Data from these satellites is transmitted in formats similar to GOES and Meteosat. GMS resolution is 1.0 kilometer directly beneath the satellite.¹²

The Russian GOMS system will eventually consist of three spacecraft in a geostationary orbit, which collects visible and infrared images and continuous weather observations. GOMS resolution is 2.5 kilometer directly beneath the satellite.¹³

Feng-Yun-2 (FY-2) is China's geostationary meteorological satellite. It takes visible and infrared images hourly. The spacecraft is quite similar to the Japanese GMS-5 satellite. The first FY-2 satellite exploded before launch, destroying the vehicle. The Chinese Meteorological Administration launched a FY-2 in 1997. In 1998, FY-2 ceased transmission of images due to a problem with the antenna on the spacecraft. When operational, FY-2 satellite data is open for international users.¹⁴ The available geostationary METSATS are depicted in table 1.

Table 1. Available Geostationary Weather Satellites and Status

Satellite program	Satellite	Longitude	Country	Launch Agency	View	Comment
METEOSAT	METEOSAT-7	0°	International	ESA	Eastern Atlantic, Europe, Africa	High resolution images encoded
INDOEX	METEOSAT-5	63°E	International	ESA	Asia, Indian Ocean, Africa	High resolution images encoded
GOMS	GOMS-1 (ELEKTRO)	76°E	Russia		Asia, Indian Ocean, Eastern Africa	Images intermittent
INSAT	INSAT-3	90°E	India		<u>Asia, Indian Ocean</u>	All images encoded
Feng-Yun	Feng-Yun-2B	105°E	China		Asia, Indian Ocean, Australia	Satellite Failed
GMS	GMS-5	140°E	Japan		East Asia, Western Pacific	Satellite Failing
GOES (WEST)	GOES-10	135°W	USA.	NASA	Eastern Pacific, North America	
GOES (EAST)	GOES-8	75°W	USA.	NASA	North America, Western Atlantic	

The next literature area reviewed were the sources on space policy in the US. The two prime documents to support this area are the 1996 US *National Space Policy*¹⁵ and the *DOD Space Policy*.¹⁶ The documents say the US expects to maintain a space leadership role by supporting a strong, stable and balanced national space program that serves our national security, foreign policy, economic growth, and scientific and technical excellence. The US will pursue greater levels of partnership and cooperation in national and international space activities and work with other nations to ensure the continued exploration and use of outer space.

Additional national security space policy is cited in the *Report of the Commission to Assess United States National Security Space Management and Organization*.¹⁷ This

report provided the Commission's assessment of the organization and management of space activities in support of US national security. Members of the Commission were appointed by the chairmen and ranking minority members of the House and Senate Armed Services Committees and by the Secretary of Defense in consultation with the Director of Central Intelligence.

NOAA discussed policy in the report *International Coordination of and Contributions to Environmental Satellite Programs*.¹⁸ The paper provided an overview of US policy on international cooperation in environmental satellites. Other international organizations used for cooperation and coordination in remote sensing are outlined. Contributions by the US to planned foreign programs are addressed as well.

Air University discussed policy in the report *SPACECAST 2020, Volume 1*.¹⁹ The study produced a series of white papers, which addressed future space capabilities. Volume I includes unclassified white papers on twenty first century weather support.

The Naval War College discussed policy in the report *United States National Space Policy and Its Implication on the Operational Commander*.²⁰ The goals established in the policy statement clearly link our space program to national security. In addition, it placed emphasis on commercial space development for national security, which leads to the proliferation of commercial space systems, including weather.

NOAA discussed policy in the report *NOAA: Civil Assets for Department of Defense Use*.²¹ This report describes the civilian satellite and ground station assets owned by NOAA and documented the existing relationship between NOAA and the DOD as a basis for DOD use during times of declared national emergency. NOAA is legally required to coordinate with DOD and assist in planning for DOD's wartime duties.

The fourth literature research area available covers the cost associated with the various satellite systems, and began with the General Accounting Office discussing costs in the report *National Space Issues: Observations on Defense Space Programs and Activities*.²² The DOD plans to spend \$70 billion during the next five years on military space programs. This represents 5.7 percent of DOD'S total planned military budget.

The Office of Technology Assessment discussed costs in the report *Reducing the Costs of Collecting Meteorological Data: A Workshop Summary*.²³ Information about the Earth obtained from satellite systems assists NOAA and the DOD in conducting its legislatively mandated programs. The report summarized the technical characteristics of the GOES, POES, and DMSP systems and outlines their planned development.

Advisory Group for Aerospace Research and Development discussed costs in the report *TACSATS for NATO*.²⁴ Tactical satellites, called TacSats, have the potential to offer significant advantages. Strategic satellites are expensive and are limited in number. The purpose of this advisory report was to demonstrate that TacSats possess the potential to enhance and enlarge the essential information. Affordability is achieved by obtaining the needed space assets in smaller incremental quantities than expensive and large strategic satellites. Responsiveness is accomplished by shorter revisit times permitted by a greater number of satellites, since they are affordable, in optimized orbits.

¹Department of the Air Force, AFDD 45, *Aerospace Weather Operations* (Washington DC: Government Printing Office, August 1994), 1.

²Department of the Air Force, AFD 15-1, *Atmospheric and Space Environmental Support* (Washington DC: Government Printing Office, October 1993), 1.

³Department of Defense, the Joint Staff, JD 3-59, *Joint Doctrine for Meteorological and Oceanographic Support* (Washington DC: Government Printing Office, December 1993), II-2.

⁴Integrated Program Office, *National Polar-orbiting Operational Environmental Satellite System Integrated Operational Requirements Document* (Washington DC: Government Printing Office, December 2002), 15.

⁵USAF's Phillips Lab, *Global Weather Awareness* (Hanscom AFB: United States Air Force: 11 May 1996), 15.

⁶National Oceanic and Atmospheric Administration, National Environmental Satellite Data and Information Service, *Federal Agency Satellite Requirements* (Washington DC: Government Printing Office, January 2003), 35.

⁷World Meteorological Organization, *Operational Environmental Satellites* (New York, NY: World Meteorological Organization, January 2003); Internet; accessed on <http://www.wmo.ch>

⁸Russian Hydrological, *Environmental Satellite Meteor* (Moscow, Russia: Russian Hydrological, January 2003); Internet; accessed on <http://sputnik.infospace.ru/meteor/engl/meteor.htm>.

⁹Integrated program Office, *National Polar-orbiting Operational Environmental Satellite System* (Washington DC: Government Printing Office, December 2002); Internet; accessed on <http://npoeslib.ipa.noaa.gov>.

¹⁰National Oceanic and Atmospheric Administration, National Environmental Satellite Data and Information Service, *NOAA Satellites* (Washington DC: Government Printing Office, January 2003); Internet; accessed on <http://www2.ncdc.noaa.gov/docs/klm>.

¹¹Europe's Meteorological Satellite Organization, *Meteosat and Meteosat Second Generation Satellites* (Darmstadt GE: European Space Agency, January 2003); Internet; accessed on <http://www.eumetsat.de/en/area1/topic1.html>

¹²National Atmospheric and Space Administration, *Geostationary Meteorological Satellite Platform Document*. (Washington DC: Department of Commerce, January 2003); Internet; accessed on http://daac.gsfc.nasa.gov/PLATFORM_DOCS/gms_source.html

¹³Space Monitoring Information Support laboratory, *Geostationary Operational Meteorological Satellite*. (Moscow, RU: SMIS IKI RAN and SRC PLANETA, January 2003); Internet; accessed on <http://sputnik.infospace.ru/goms/engl/goms.htm>.

¹⁴National Atmospheric and Space Administration, *Feng-Yung Meteorological Satellite Platform Document* (Washington DC: Department of Commerce, January 2003); Internet; accessed on http://daac.gsfc.nasa.gov/PLATFORM_DOCS/fy-2_source.html.

¹⁵White House National Science And Technology Council, *National Space Policy, Fact Sheet* (Washington DC: Government Printing Office, September 19, 1996); Internet; accessed on <http://www.fas.org/spp/military/docops/defense/d310010p.htm>.

¹⁶Defense Department, *DOD Space Policy* (Washington DC: Government Printing Office, September 19, 1999); Internet; accessed on <http://www.fas.org/spp/military/docops/defense/d310010p.htm>

¹⁷Donald H. Rumsfeld, *Report of the Commission to Assess United States National Security Space Management and Organization* (Washington DC: Government Printing Office, 11 January 2001); Internet; accessed on <http://www.defenselink.mil/pubs/space20010111.html>.

¹⁸National Oceanic and Atmospheric Administration, *International Coordination of and Contributions to Environmental Satellite Programs* (Washington DC: Government Printing Office, Jun 85), 65.

¹⁹Air University, *SPACECAST 2020, Volume 1* (Maxwell AFB: United States Air Force: June 92), 86.

²⁰Naval War College, *United States National Space Policy and Its Implication on the Operational Commander* (Providence RI: United States Navy: 13 June 1997), 19.

²¹National Oceanic and Atmospheric Administration, *NOAA: Civil Assets for Department of Defense Use* (Washington DC: Government Printing Office, August 1990), 49.

²²White House National Science And Technology Council, *National Space Issues: Observations on Defense Space Programs and Activities* (Washington DC: Government Printing Office, August 1994), 34.

²³Office of Technology Assessment, *Reducing the Costs of Collecting Meteorological Data: A Workshop Summary* (Washington DC: Government Printing Office, June 1995), 20.

²⁴Advisory Group for Aerospace Research and Development, *TACSATS for NATO* (Bressels, Belgium: North Atlantic Treaty Organization, February 1994), 73.

CHAPTER 3

RESEARCH METHODOLOGY

The primary research question asked if non DOD meteorological satellites could be used to meet DOD environmental requirements. Weather satellites are critical to the military's ability to meet the requirements of the *National Military Strategy*. The design for this project revolves around a comparative assessment model of systems that can accomplish the environmental remote-sensing mission. The path to answering the research question sought to accomplish the following:

- (1) What are the DOD requirements for remote sensing of environmental data?
- (2) What is the current ability of the DOD to meet the environmental and weather data observational requirements?
- (3) What are the available civil, foreign, and commercial meteorological satellites, along with their capabilities, limitations, and data reliability, to meet DOD requirements?
- (4) What is the US and DOD policy on the use of civil, foreign, and commercial satellites and what are the available agreements, which would allow METSAT collaboration and minimize the impact the risks of using these assets?
- (5) What are the cost benefits of using civil, foreign, and commercial METSATs to meet DOD requirements? Is cost a driver for policy and use, in order to analyze a balance of risk against the cost-benefit of using alternative METSATs?

Since the basis of the thesis conclusion was a comparative assessment built upon the DOD's requirement for weather data, the study evaluated DOD requirements and assessed both the spatial and temporal resolution and accuracy of the data. The thesis also

explored the degree to which the requirements were absolutely needed verses desired, commonly referred to in the DOD as threshold and objective requirements.

The research methodology for this thesis was comprised of three phases in determining if foreign or commercial meteorological satellites should be included to meet DOD environmental requirements. To determine if other than DOD-owned METSATs should be included in joint policy to meet DOD environmental requirements, several subordinate issues were analyzed.

Phase one included analysis of all available resources appropriate to answering the thesis question and the associated supporting questions. Additionally, the first phase identified the basic DOD requirements for remote sensing of environmental data and evaluated the current ability of the DOD to meet these requirements. The second phase identified the capabilities to observe weather using meteorological satellites, looking specifically at the capabilities and limitations of various METSATs and investigated the available foreign meteorological satellites, along with their capabilities, limitations, and reliability, to meet the requirements. The third phase researched the policy and available agreements which allow US and foreign METSAT collaboration and impact the risks of using foreign assets and concluded by identifying the cost benefits of using foreign METSATs to meet DOD requirements. Phase three also looked at evolving national space policy, with an emphasis concerning foreign METSATs and any potential risks to DOD operations, in order to analyze a balance of risk against the cost-benefit of using foreign METSATs.

As previously discussed, the paper sought to analyze all pertinent information relative to the topic within the time limitations available to the student. This included, for

the purposes of this paper, identifying the requirements for observing weather with meteorological satellites and defined the roles meteorological satellites play in supporting military operations. Since current military weather systems do not provide full-time continuous coverage, the thesis investigated how a mix of military and civil assets could provide increased coverage and discussed developing architecture for a space-observing network. In discussing requirements, the thesis identified what kind of information the DOD requires and at what resolution it is needed. The thesis investigated whether civilian METSATS are adequate to meet DOD requirements. Further, the thesis researched the current available transmission times for DMSP, civil, foreign, and commercial weather satellites to determine if they were adequate. Lastly, the thesis probed the mixture of polar-orbiting and geostationary METSATS.

The second phase of the development sought to use information obtained during the initial research to define the discussion framework. From that baseline, the paper identified the capabilities and limitations of the meteorological satellites and their ability to meet requirements laid out in phase one. The thesis probed where space systems have limitations with respect to when, where, and what kind of information they can sense. Next, there was discussion of the need for encrypted data from military satellites.

Finally, phase three looked at national space policy, the benefits in terms of costs and synergy with US allies, and potential risks to using foreign METSATS. For example, the thesis examined how treaty limitations, political considerations, and other potential international events could impact DOD operations.

CHAPTER 4

ANALYSIS

The structure of the thesis analysis is broken into three broad categories. The first category was the identification of the benefit of collecting weather observations from METSATS and the available system to collect the data, which was discussed in detail in chapter 2. The second category of analysis identified the types of orbits and their capabilities and limitations in providing accurate observations. This analysis, along with the DOD requirements, combined to provide an evaluation of the ability of the DOD to meet current needs of the military and an analysis of the requirement shortfall. The third general category of analysis investigated guidance, discussions, direction, and policy with regard to the US space policy, risk assessment, and cost considerations.

The thesis analysis began with an identification of the benefits of collecting weather observations from METSATS. The field of meteorology entered the space age on 1 April 1960. Since then, METSATS with increased capabilities have been deployed to provide real-time cloud imagery and sounding data. Various types of sensors are used to detect weather and its changes. Visual sensors take pictures of cloud formations, land, and water, while infrared sensors provide data on the temperatures of the water, land and clouds and determine the temperature of the atmosphere. Seventy percent of the earth's surface is covered by water where few surface observations occur, which provides a critical advantage for METSAT coverage. Before the deployment of METSATS, many areas had no observations and weather impacts to military operations could not be assessed.

METSATs do not replace surfaced-based observations, but rather compliment and augment them. Surface observations are critical for current weather conditions. Only in-situ observations on land, on the oceans, or aloft by balloons provide direct precise measurement (in-situ) of conditions. The challenge is a lack of in-situ observations. METSATs do not measure conditions directly. Instead, they use instruments that either take visible and infrared pictures or soundings. They accomplish this with sensors that observe various discrete bands of the electromagnetic spectrum. METSATs are the only alternatives to thousands of monitoring stations around the world. Therefore, without space systems, data can be difficult to obtain, especially in areas where access is limited due to military or political restrictions.

Analysis of weather is a critical step in the intelligence preparation of the battlefield for the military. Weather and its effects on the environment and terrain have impacted the conduct of military operations throughout history. Knowledge of the weather along with accurate predictions of future conditions is a definite advantage in military operations. Weather data plays a crucial role in planning and conducting all military operations ranging from locating cloud gaps for aerial refueling to determining visibility prior to reconnaissance flights. The importance of weather data from satellites is firmly established in the efficient conduct of military operations. Satellite weather pictures are used for forecasting when conditions are favorable for friendly forces and the impact of weather on the effectiveness of weapons and the mobility of forces.

METSATs sensors provide situational awareness and allow geographical access to areas the military does not have direct access to in-situ observations. Weather data from these areas can be critical. For example, weather conditions developing in China

have a strong influence on the weather that will occur on the Korean peninsula. Although China reports some weather conditions through international civil channels, the reports are sparse, inaccurate, inconsistent, and worse, may be discontinued during a conflict in Korea. Satellites provide a way to gather weather data quickly over large areas using our own sensors but without violating a country's airspace.

Most METSATs are civil systems, even in the case of foreign weather satellites and the organizations operating the systems routinely share data. The US, Russia, Japan, China, Europe, and India currently have national, civil METSATs in operation. These systems were introduced in chapter 2. DMSP is the only military METSATs system and is merging with a civil system in the future. Additionally, there are many research and development (R&D) environmental satellites available, like National Atmospheric and Oceanographic Administration's (NOAA) scientific systems. While the accuracy of the observations from R&D METSATs meet DOD requirements in some cases, the concept of operations for scientific satellites is not conducive for the timely distribution of data to meet operational requirements. Additionally, the commercial METSAT programs are only conceptual at this time and will not be available until after the 2010 time frame and outside the scope of this thesis. Further, the cost benefit of commercial systems over the United States is limited by the *Land Remote Sensing Policy Act of 1992*. Subchapter VI, Prohibition Of Commercialization Of Weather Satellites, Section 5671 states "neither the President nor any other official of the government shall make any effort to lease, sell, or transfer to the private sector, or commercialize, any portion of the weather satellite systems operated by the Department of Commerce or any successor agency". In future considerations, Section 5672 states "Regardless of any change in circumstances

subsequent to October 28, 1992, even if such change makes it appear to be in the national interest to commercialize weather satellites, neither the President nor any official shall take any action prohibited by section 5671 of this title unless this subchapter has first been repealed.”¹ Based on this act, civilian government METSATs will be available in the future at no cost to the DOD. In view of National Space Policy cost considerations then, commercial METSATs do not provide a cost effective solution over the US. Therefore, the only METSATs available for consideration in meeting DOD requirements in the near to mid-term are foreign-national, civil systems.

Although civil METSATs performed well in the past, they are not hardened against military hostile action. Only the US military has DMSP METSATs that are hardened to enhance their survivability. Further, DMSP, as well as NPOESS in the future, transmit encrypted data, which cannot be used by unapproved users.

The second category of analysis identified the types of space orbits and their capabilities and limitations in providing accurate weather observations. The wide-ranging view afforded from satellites makes it possible to observe weather over a large area from an overhead perspective. METSATs can be found in two types of orbits: geostationary to give the regional big picture and polar sun synchronous, to collect worldwide data closer to the earth. The advantages of using polar orbiting satellites and high altitude geostationary orbiting satellites are to counterbalance the disadvantages of the other type of orbit. Using satellites that are in both types of orbits, it is possible to keep 100 percent of earth almost constantly under observation and provide the most accurate data available to merge with the ground weather system data. This is a fundamental concept of space operations due to orbital mechanics. Neither of the two orbits is capable of meeting DOD

requirements by themselves. These concepts are more fully explained below and lead to the conclusion that the military must develop an architecture concept of METSATs to meet requirements.

In order to evaluate a METSAT's capabilities and limitations in providing accurate observations, one must understand METSAT's ability to gather information about the condition of the earth's land, sea, and atmosphere by remote sensing. METSATs accomplish this with sensors, which observe the earth through the electromagnetic spectrum. When the data from space is merged with ground and airborne sensors, the resultant products are significantly better than those from only one source.

The electromagnetic spectrum provides the medium exploited by METSATs. Regions of the spectrum are selected to optimize collection for certain categories of information. Sensors carried on METSATs sense electromagnetic energy across the spectrum. Each sensor is designed to detect in a specific, narrow band of the spectrum.

The benefits afforded space systems and the capabilities of the electromagnetic sensors are the basis for the DOD requirements, which are contained in MJCS 154-86 and in the *NPOESS Integrated Operational Requirements Document* (IORD). Since the environment impacts a variety of DOD systems and missions, maintaining situational awareness concerning those weather impacts requires relevant information. Relevant, timely, and accurate weather observations with sufficient spatial and temporal coverage enable DOD operations not only to maintain situational awareness, but also use information to mitigate and exploit its effects. Accordingly, obtaining the right information requires development of appropriate environmental data monitoring capabilities. In order to accomplish this task, requirements are articulated in the various

DOD Operational Requirements Documents and related documents, as outlined in Appendix A.

The DOD requires the ability to rapidly and accurately monitor on a global basis six key environmental parameters (atmospheric vertical moisture profiles, atmospheric vertical temperature profiles, cloud imagery, sea surface temperature, soil moisture and surface/boundary layer winds) and twenty-five non key environmental parameters. A global coverage capability must be sustained. Global revisit times need to be minimized to meet objective requirements for temporal and spatial accuracy. The timeliness of data dissemination to DOD forecasting centers is another requirement for temporal resolution.

After an analysis of the benefits of METSAT's observations and a summary of the requirements, the thesis author reviewed the ability of METSATS to meet those requirements beginning with an analysis of the orbits. Because space systems have unrestricted over flight of otherwise denied areas, they can gather information about weather in an enemy's or potential enemy's territory. METSATS allow a systematic observation and ability to monitor weather conditions at great distances. Therefore, METSATS advantages are their ability to provide worldwide coverage, access non permissive regions, and enhance planning capabilities by providing updated information. More significantly, METSATS provide near real time data.

The key limitation of these systems is simply based on limitations dictated by the satellite's orbit. As discussed previously with remote sensing and METSATS, the LEO orbit gives the best resolution and worldwide coverage, but it does not provide continuous coverage of an area like a geostationary satellite. The cost of satellites prohibits a proliferation of METSATS as exists with communications satellites.

As discussed previously, there are two types of orbits used by METSATs: (1) low-earth, polar and (2) geosynchronous. Understanding the capabilities and limitations of METSATs and the orbits they are in is crucial to analyzing the capability to meet DOD requirements. A polar orbit is generally considered to have an apogee, maximum altitude, of no more than approximately 530 miles. The advantages of this type of orbit are high resolution due to a low orbit, the ability to observe the entire earth from one satellite, and they are relatively inexpensive to launch. This orbit provides global daily coverage with higher resolution than geostationary orbit. Additionally, these satellites operate in a sun-synchronous orbit, providing a continuous sun angle for the scan, which means the satellite passes the same point at the same time each day, which enables regular collection and long-term comparisons. The greatest benefit polar-orbiting satellites provide is a global view of earth. The orbit is fixed in space, and the earth rotates underneath. Therefore, a single METSAT in a polar orbit, provides coverage to the entire globe, although there are long periods out of view. A constellation with two satellites, like DMSP, provides a picture of the same area at least every six hours.

There are disadvantages to the polar orbit, which must be considered. The satellite is in view of the ground for a short period of time as it passes quickly overhead and the footprint can be small. A polar satellite cannot provide continuous coverage to a specific area. In many orbits, the satellite may orbit the Earth many times before it passes within view again. Because of low altitudes, atmospheric drag significantly limits the lifetime of these satellites. Lastly, maintaining constant communications with a polar satellite requires a large number of ground stations located around the world.

The second type of orbit available for METSATS to meet DOD requirements is a geosynchronous orbit, which has a period equal to that of earth's rotation (one day). A satellite with this period is considered to be in a high altitude orbit of about 22,300 miles.

A geostationary orbit is a special kind of geosynchronous orbit. To an observer on the ground the satellite appears to be stationary in the sky. The most significant advantage is that the satellite provides continuous coverage of specific areas of the Earth and antennas do not need to track the satellite. These orbits provide a regional view for coverage of weather events. However, it provides distorted images of the polar-regions with poor spatial resolution from the great height at which observations are made.

The footprint of a geostationary satellite is large and covers almost one-third of the Earth's surface, but the effective range is twenty percent of the earth's surface and they cannot see to the polar regions. The signal travels through much more atmosphere and degrades the use of geostationary satellites. Since the resolution of geostationary METSATS degrades significantly away from directly under the satellite, these systems do not meet DOD requirements pole-ward of 35 degrees. Therefore, geostationary satellites produce lower resolution images than polar orbiters, since the image quality degrades as distance and angle from the point directly under the satellite increases. This concept is explained more fully below under the satellite accuracy discussion of NADIR. Therefore, both practically and to meet DOD requirements, five geostationary METSATS are required to adequately observe around the world at the equator.

The thesis analysis next reviewed the ability to meet requirements with an analysis of the METSAT accuracy. There are key terms that must be understood when discussing multi-spectral imagery to understand the resolution of any given satellite.

These terms require discussion to understand why any given METSAT, including DMSP and NPOESS, are capable or incapable of meeting DOD requirements. Each term gives different parameters of a system.

As discussed previously, METSATS record electromagnetic radiation. The radiation detected by a system may be solar reflected energy or thermal energy emitted by an object. A portion of the reflected radiation exits through the atmosphere and is recorded. The energy is received in the form of individual brightness values or picture elements or pixels. In a digital system, a pixel represents an area on the Earth's surface.

Spatial resolution is a way of stating the size of pixels for a digital system. Pixel size is a direct indicator of the spatial resolution of the sensor. Spatial resolution is the smallest separation between two objects on the ground that can be detected as a separate object. With current systems, spatial resolution is referred to in meters and each pixel will sample a square area on the ground in terms of meters. Spatial resolution is critical to meeting DOD visual and infrared imagery requirements for operations requiring high-resolution. The best spatial resolution is available from DMSP and NPOESS.

Spectral resolution refers to the bandwidth of a sensor: generally, the narrower the band and the higher the number of bands, the better the spectral resolution. Spectral resolution is critical to meeting DOD vertical sounding requirements. The best spectral resolution is available from R&D METSATS but both polar-orbiting and geostationary systems meet DOD requirements.

Temporal resolution refers to the time it takes an imaging system to return to an area to collect another image. It is essentially a satellite's revisit time or refresh rate. All imagery collected provides a snapshot of an area. Understanding changing conditions

may require a number of images. Temporal resolution must be considered critical for weather data from any source since the environment is dynamic and always changing. Temporal resolution is critical to meeting DOD data refresh needs. The best temporal resolution is available from geostationary systems.

Radiometric resolution refers to the sensitivity of a spectral band. Most METSATs record an image in each band in 256 levels of brightness. One multi spectral imager aboard POES, called the Advanced High Resolution Radiometer, collects imagery in 1,024 levels of brightness. Radiometric resolution is critical in support of measurements and signals intelligence, but is not specified in DOD requirements. NOAA's POES and the National Atmospheric and Space Administration's (NASA) R&D systems have the greatest radiometric resolution even though the spatial and temporal resolution is significantly less than others.

An additional consideration of accuracy is viewing geometries, which is the NADIR concept mentioned earlier. Viewing geometries are available in two varieties: off-nadir/directional viewing and nadir viewing. Nadir refers to the point on the planet directly below the satellite. Nadir imagers look straight down at the Earth. Directional systems have the ability to view the Earth away from the ground track of the satellite's orbit or off-nadir. The off-nadir systems' capabilities, like geosynchronous METSATs, increase the viewing area and temporal resolution. Distortions in nadir imagers are due to Earth curvature and the effect of imaging across a spherical surface, which decrease spatial resolution and imagery accuracy. DMSP provides a spatial resolution of 0.5 kilometer across the width of the scan regardless of viewing geometries. NPOESS will provide the same capability; however, no other available weather satellites provide the

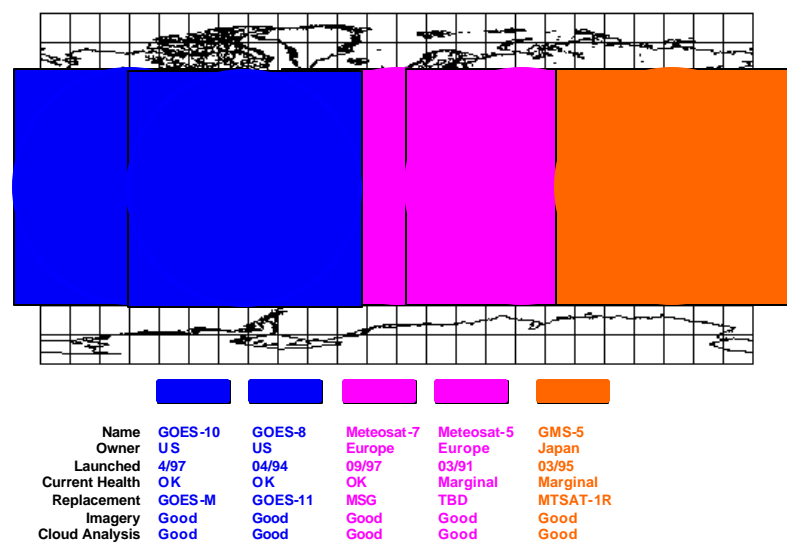
same capabilities. Therefore, DMSP and NPOESS provide a unique spatial resolution capability, due to viewing geometries, to meet DOD requirements.

The analysis of the two types of orbits and their capabilities and limitations in providing accurate observations, along with the requirements, provide the basis for evaluation of the ability to meet current needs and an estimation of the requirement shortfall. DMSP, and in the future NPOESS, is capable to meet DOD requirements for spatial and spectral resolution. However, due to the nature of a polar-orbiting satellite, the thesis analysis identified the requirement shortfall of DMSP and NPOESS, which is temporal resolution. The poor refresh rates are due to orbital mechanics and a polar-orbiting satellite's inability to continually monitor a specific location. Since geostationary METSATS provide continuous regional coverage, they meet the temporal requirements for the regions observed. However, geostationary METSATS do not provide worldwide coverage, nor do they meet the spatial resolution requirements due to the viewing geometries discussed. The analysis, in turn, identified a potential solution of using an architecture of DMSP, NPOESS and civil and foreign geostationary METSATS to meet DOD objective requirements.

Since temporal resolution is an objective goal, threshold requirements are met using DMSP. Recalling from chapter 2, DMSP operates in a two satellite constellation and each spacecraft collects high-resolution visible and infrared cloud imagery and other specialized data from a 2,800 kilometer wide area beneath it. However, there is a shortfall for objective requirements due to orbital mechanics. A polar orbiting system, no matter how capable, is unable to maintain continuous observation of a region. Only geostationary systems provide continuous coverage. There are five reliable geostationary

systems (GOES East and West, GMS-5, Meteosat 5 and 7), which provide worldwide coverage. The coverage from the geostationary METSATs is shown in figure 2.

Figure 2: Available Geostationary METSAT and Coverage



Historically, the DOD used US civilian geostationary METSATs for resource protection and other military applications. Further, there are other non-US METSATs with comparable capabilities to the GOES system and the DOD used allied METSATs to augment data available from DMSP. Examples include using the European Meteosat to support Operation Enduring Freedom and a Japanese GMS-5 to provide data for typhoon reconnaissance over the Western Pacific.

Therefore, the DOD requires an architecture to meet objective requirements, preferably two polar and five geostationary systems using the two DMSPs, the two US GOES (GOES East and West), the two Meteosat systems (Meteosat 5 & 7), and the

Japanese GMS. While other geostationary METSATs are available, namely the Russian, Chinese, and Indian, the systems are extremely unreliable and undesirable. Further, the numerous R&D satellites available are undesirable due to timeliness.

NPOESS builds increased capability for the future and a builds timelier three-system constellation in a polar orbit. NPOESS is a triagency weather satellite program that provides timely, high-quality weather information as the nation's single source of global weather data. Per Presidential Decision Directive/National Science and Technology Council-2 signed in May 1994, the DOD, DOC, and NASA are combining DSMP and POES to create NPOESS, which will both support military operations and protect national resources.²

In summary, the thesis thus far analyzed the benefit of METSATs, investigated the available systems, identified the orbits to provide accurate observations and DOD requirements, evaluated the ability of the DOD to meet current needs, and isolated the requirement shortfall. This analysis brings the conclusion that the DOD requires a constellation of METSATs to meet threshold objectives. However, the military has not adjudicated a requirement for a METSAT architecture to meet DOD requirements. Before a requirement should be submitted, an analysis is required of the policy and guidance concerning non-military assets to meet these requirements

The third general category of analysis investigated guidance, discussions, direction, and policy with regard to the US space policy, risk assessment, and cost considerations. The analysis of national and DOD policy provided the strength of the thesis investigation providing clear direction on the use civil, international, and commercial space assets. Further, the policy provides commentary of both cost

considerations as well as risk mitigation for national security. The analysis began with a broad summary of US policy, discussed DOD and DOC responsibility, and then directly addressed policy statements on the use of civil assets, collaboration with international partners, and the encouragement commercial ventures. The analysis then addressed DOD policy along the same lines, but analyzed details concerning risk to national security.

The *National Space Policy* defined the principles of the US space program, examined how the US conducts its space programs, and outlined the basic tenets of US policy. Space policy evolved based on goals and objectives of the nation, budget constraints, previous space policies, current programs, international law, and treaty obligations.³ Today, the *National Space Policy* states the primary goal of space activity is to ensure US security and addresses activities necessary for national defense. The current *National Space Policy* is dated September 1996. It addressed objectives for the space program, the national defense, and federal policies⁴.

Foremost, the policy stated the US government will continue to use earth observation systems to collect environmental data and will seek mutually beneficial cooperation with US commercial and other national and international Earth observation systems to: (1) define an integrated global observing strategy; (2) develop US Earth observing systems in coordination with other national and international systems to ensure efficient collection; and (3) obtain Earth observation data from non-US sources, consistent with national security requirements.⁵ The policy first addressed the responsibilities of various cabinets. The policy ensures NASA will focus its research and development efforts in fundamental physical sciences, earth observation to better understand global change, and to develop new technologies in support of US government

needs. The DOC, through NOAA, has the lead responsibility for managing federal space-based civil operational Earth observations necessary to meet civil requirements.⁶ In this role, the DOC will: (1) acquire environmental data, and (2) consolidate operational US Government civil requirements and operate METSATS.⁷ The policy states the DOD will pursue integrated satellite control and will coordinate with other departments and agencies to foster the integration of satellites for all space activities.

The *National Space Policy* stated the US would conduct international cooperative space-related activities that achieve benefits for the nation. Further, the US government will: (1) develop and operate METSAT systems, (2) research and develop advanced METSAT observation technologies to improve the quality and reduce the costs of Earth observations, and (3) support the development of US commercial earth observation capabilities by including partnerships with industry.⁸ In executing this cooperation, the policy stated a NOAA-led system could easily maintain and even improve international cooperation in environmental data exchange. However, since NOAA plans to use foreign satellites as part of the converged program, the policy recognized the DOD might be reluctant to rely upon foreign satellites for important data. Finally, the *National Space Policy* stated the US government agencies shall purchase commercially available space goods and services to the fullest extent feasible, where "feasible" means services meet mission requirements in a cost-effective manner.⁹

The analysis then considered DOD Policy. *DOD Space Policy*, while consistent with the national policy, focused on operational capabilities that enable the military to fulfill national security objectives. Key features of the policy are: (1) assuring the availability of critical space capabilities necessary for executing national security

missions; (2) planning focuses on improving the conduct of national security space operations, assuring mission support, and enhancing military support; (3) maximizing civil and commercial capabilities, including the use of allied and friendly capabilities, yet consistent with national security; and (4) providing assured, cost-effective access to space.¹⁰

To execute the mission, the DOD Policy required space architectures structured to take full advantage of defense, civil, commercial, allied, and friendly space capabilities. DOD planning should emphasize responsiveness and the elimination of vulnerabilities that could prevent mission accomplishment. In considering requirements, the DOD is expected to identify augmentation of the space force structure by civil, commercial, allied, and friendly space systems. In this manner, an integrated architecture addressed missions to eliminate unnecessary stove piping of programs, minimize unnecessary duplication of functions, achieve efficiencies in acquisition and operations, and improve support to military operations and national security.¹¹ Overall and as mentioned previously, the space architecture should be structured to take full advantage, as appropriate, of defense, civil, commercial, allied, and friendly. Finally, space programs and activities are required to be responsive to mission area shortfalls, validated operational needs, and operational requirements.¹²

Additionally, the DOD policy addressed international cooperation and partnerships in space activities with the US's allies and friends should be pursued to the maximum extent feasible, just as the national policy required. The intention of the cooperation is to forge closer security ties with US allies and friends, enhance mutual and collective defense capabilities, and strengthen US economic security. Further, the

international cooperation is expected to strengthen alliances and improve interoperability between US and allied forces to operate in a combined environment in a more efficient and effective manner. However, the DOD policy emphasized the cooperation should be pursued in a manner, which protects US national security.

The next area of the thesis analysis was the secondary question: Are alternate METSATS reliable for continuous data to meet the environmental requirements? *National Space Policy* addressed the concept of oversight and recognized the DOD required “some mechanisms to ensure their requirements continue to be met.”¹³ US Policy indicated to execute the mission, space architecture should be structured to take full advantage of the available systems and in turn provide a measure of security for data reliability. Further, agreements exist between NOAA, under the Department of Commerce, and Europe’s EUMETSAT consortium¹⁴ and India¹⁵, as well as an agreement with the Japan Meteorological Agency¹⁶. These documents provide the DOD the basis for the required oversight and some mechanisms to ensure their requirements continue to be met. These agreements provide data reliability for both parties. For example, EUMETSAT proposed¹⁷ a satellite deployment strategy, with control maintained by the satellite owner, which could be useful in alleviating the affects due to satellite failures. This concept would provide overlap satellite coverage with a resultant “fail-soft” global network.¹⁸

The last consideration analyzed to mitigate DOD risk is included in the implementation details from NPOESS, which involve placing DOD user and acquisition experts in NOAA. These procedures would allow the management of DOD-unique parts of the program and establish an interagency oversight so requirements are adequately met.¹⁹ As an example of the potential risk, recently it was determined that the planned

European polar-orbiting satellite proposed to support NPOESS, would not be capable of meeting US threshold requirements. The US is now forced to budget to sustain the entire satellite constellation with NPOESS diminishing some cost benefits. However, the precedent was set that if US threshold requirements will be met, the US is willing to achieve partnerships with allies.

The last area of the thesis analysis considered the secondary question of: What are the cost considerations of using alternate METSATs to meet DOD requirements? US policy is clear in that cost is a significant consideration to space. Specifically, the national policy states, “Civil, international, and commercial cooperation . . . shall be pursued . . . in order to share or reduce costs, minimize redundant capabilities, minimize duplication of missions, achieve efficiencies in acquisition and operations, and improve support to military operations.”²⁰ DOD policy reiterates this point by stating space concepts of operations should “provide assured, cost-effective, responsive access to and use of space.”²¹ While these first two statements address space policy in general, US policy addresses METSATs specifically. It states, “the US Government will seek to consolidate Earth observations to reduce overlaps where cost-effective and consistent with US space goals.”²²

Both National and DOD policy identify cost as a tremendous factor in acquisition decisions. Policy states cost will be considered in all architecture development to ensure organizations understand cost drivers and weigh requirements against costs. Therefore, federal cooperation with the civil and commercial sectors will be pursued to share or reduce costs, minimize redundant capabilities, minimize duplication of missions, achieve efficiencies in acquisition and operations, and improve support to military operations.²³

The driving force behind this effort is clearly the desire to reduce costs. Additionally, further cost reduction could be achieved through greater international participation. According to Dr. Ray A. Williamson of the Office of Technology Assessment: "Greater international collaboration will eventually be needed in order to reap the benefit from the world-wide investment in remote sensing."²⁴ NOAA is working on arrangements in its program by asking the Europeans to assume a greater role. An agreement, in principle, has been reached between NOAA and EUMETSAT. Cooperation with the Europeans is an important component of cost-efficient operations and is the first step to a truly international environmental satellite observing system.

However, the greatest evidence that cost is a driver in determining the technical solutions was the decision to merge the military and civilian polar-orbiting METSATS. In accordance with PDD/NSTC-2, the DOC, DOD, and NASA established a single, converged system in NPOESS to satisfy civil and national security requirements and are required work together to develop, demonstrate, and transition US METSAT systems.²⁵

Brigadier General Robert C. Hinson, USAF Space Command Director of Operations, and Robert S. Winokur, NOAA's assistant administrator for satellite information services, stated, "This merger is a force-multiplier, maximizing efforts of personnel and material resources and we'll realize savings that can be applied to other important military space programs. The transition of operations marks another major, important milestone in our commitment to implementing weather satellite convergence, and building a true operational partnership to satisfy the requirements of the civil and military weather community."²⁶ It is believed the proposed changes allow for a more efficient, less costly satellite program and that a strong, efficient US environmental

program is the foundation for a cooperative international system. The result will be additional environmental data collected at minimal cost. The concept provides a feasible and cost effective opportunity to accurately monitor and predict the impact of the environment. Cost savings over ten years could total about \$1.3 billion.²⁷

¹United States Code Title 15, Chapter 82, *Land Remote Sensing Policy Act of 1992*(Washington, DC: Government Printing Office, 28 October 1992); Internet; accessed on <http://geo.arc.nasa.gov/sge/landsat/15USCch82.html>.

²Integrated Program Office, *National Polar-orbiting Operational Environmental Satellite System Integrated Operational Requirements Document* (Washington, DC: Government Printing Office, December 2002); Internet; accessed on <http://www.fas.org/spp/military/program/sp97/npoess.html>.

³The White House National Science And Technology Council, *Fact Sheet on National Space Policy* (Washington, DC: Government Printing Office, 19 September 1996); Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

⁴Ibid., Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

⁵Ibid., Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

⁶Office of the Secretary of Defense, *Department of Defense Policy on Space* (Washington, DC: Department of Defense, 19 July 1999); Internet; accessed on (<http://www.c3i.osd.mil/org/c3is/spacepol>).

⁷Ibid, Internet; accessed on (<http://www.c3i.osd.mil/org/c3is/spacepol>)

⁸ The White House National Science And Technology Council, Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

⁹ Ibid., Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

¹⁰Office of the Secretary of Defense, Internet; accessed on (<http://www.c3i.osd.mil/org/c3is/spacepol>).

¹¹Ibid, Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

¹²Ibid, Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

¹³The White House National Science And Technology Council, Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

¹⁴National Oceanic and Atmospheric Administration, *Agreement Between NOAA and EUMETSAT on an Initial Joint Polar-Orbiting Operational Satellite System* (Washington, DC: NOAA, 19 November 1988) 1.

¹⁵National Oceanic and Atmospheric Administration, *MOU Between India Department of SST; NASA and NOAA for Scientific Cooperation* (Washington, DC: NOAA, 16 December 2002) 1.

¹⁶National Oceanic and Atmospheric Administration, *Arrangement Between NOAA; Department of Commerce and Japan Meteorological Agency; on Back-up of Geostationary Meteorological Satellites* (Washington, DC: NOAA, 10 May 2001) 1.

¹⁷World Meteorological Organization, *Operational Environmental Satellites* (New York, NY: World Meteorological Organization, 10 January 2001); Internet; accessed on <http://www.wmo.ch/hinsman/cgmsp03.html>.

¹⁸*Ibid.*, Internet; accessed on <http://www.wmo.ch/hinsman/cgmsp03.html>.

¹⁹Office of the Vice President, *Establish a Single Civilian Operational Environmental Polar Satellite Program Accompanying Report of the National Performance Review*, (Washington, DC, September 1993); Internet; accessed on http://www.fas.org/spp/military/program/met/npr93_npoess.htm.

²⁰The White House National Science And Technology Council, Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

²¹Office of the Secretary of Defense, Internet; accessed on (<http://www.c3i.osd.mil/org/c3is/spacepol>).

²²The White House National Science And Technology Council, Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

²³Office of the Vice President, Internet; accessed on http://www.fas.org/spp/military/program/met/npr93_npoess.htm.

²⁴Williamson, Dr Ray. *International Cooperation on Meteorological Satellites* (Washington, DC: A Office of Technology Assessment, January 2001) 12.

²⁵The White House National Science And Technology Council, Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

²⁶Air Force News, *Air Force turns over weather satellite control* (Peterson AFB, CO: USAF, Jun 2, 1998); Internet; accessed on <Http://www.fas.org/spp/military/ /html>.

²⁷Office of the Vice President, Internet; accessed on http://www.fas.org/spp/military/program/met/npr93_npoess.htm.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In considering the conclusion, the thesis reviewed the answers obtained to the primary thesis question of whether the DOD policy should include civil, foreign, or commercial METSATs to meet DOD objective environmental requirements. The first review was the benefits to collecting weather observation with METSATs, followed by the requirements available to evaluate the available solutions, including METSATs. The second review was the ability of DMSP and NPOESS to meet the requirements and the identification of a shortfall in the current technical solution. The third area was the analysis of the ability of US civil and foreign national METSATs, and determining whether they can provide the required coverage and are capable of meeting the requirements. As a conclusion to meet objective requirements, the DOD requires a METSAT architecture. Once the need for a METSAT architecture was identified, there was a review of National and DOD policy to determine what guidance is available. Lastly, the thesis reviewed how to ensure data reliability and minimize DOD risks, as well as determining if cost was a factor in identifying potential solutions.

The prime advantage of METSATs is their ability to gather data in remote or non-permissive areas, where little or no data can be obtained from surface reporting stations. This is especially important since approximately 70 percent of the Earth's surface is water and even the land areas have many regions, which are sparsely inhabited.

Since the environment impacts a variety of DOD systems and missions,

maintaining situational awareness concerning those weather impacts requires relevant information. Relevant, timely, and accurate weather observations with sufficient spatial and temporal coverage enable DOD operations not only to maintain situational awareness, but also use information to mitigate and exploit its effects. Accordingly, obtaining the right information requires development of appropriate environmental data monitoring capabilities. In order to accomplish this task, requirements are articulated in the various DOD Operational Requirements Documents and related documents.

The DOD requires the ability to rapidly and accurately observe six key weather parameters (atmospheric vertical moisture profiles, atmospheric vertical temperature profiles, cloud imagery, sea surface temperature, soil moisture and surface/boundary layer winds) and 25 non-key environmental parameters. A global coverage capability must be sustained. Global revisit times need to be minimized to meet objective requirements for temporal and spatial accuracy. The timeliness of data dissemination to DOD forecasting centers is another key requirement for temporal resolution.

The satellite's wide-ranging view makes it possible to observe weather over a large area. METSATS exist in two types of orbits: geostationary, to give the regional perspective, and polar sun-synchronous, to collect worldwide data closer to the earth. The advantages of using polar orbiting satellites and high altitude geostationary orbiting satellites counterbalance the disadvantages of the other type. Using satellites in both types of orbits, it is possible to keep 100 percent of Earth almost constantly under observation and provide the most accurate data available to merge with the ground weather system data. The shortfall currently for objective requirements is due to orbital mechanics. A polar orbiting system, no matter how capable, is unable to maintain continuous observation.

Only geostationary systems provide continuous coverage. However, neither of the two categories is capable of meeting DOD requirements by themselves.

The analysis of the two types of orbits and their capabilities and limitations in providing accurate observations, along with the requirements, provided the basis for evaluation of the ability to meet current needs and an estimation of the requirement shortfall. DMSP, and in the future NPOESS, is capable to meet DOD requirements for spatial and spectral resolution. However, due to the nature of a polar-orbiting satellite, the thesis analysis identified the requirement shortfall of DMSP and NPOESS, which is temporal resolution. The poor refresh rates are due to orbital mechanics and a polar-orbiting satellite's inability to continually monitor a specific location. Since geostationary METSATS provide continuous regional coverage, they meet the temporal requirements. However, geostationary METSATS do not provide worldwide coverage because they cannot observe the polar or high latitude regions, nor do they meet the spatial resolution requirements due to the viewing geometries discussed. This finding led to the conclusion that the military must develop an architecture concept of METSATS, a system of system, to meet requirements. The analysis identified a potential solution of using an architecture of DMSP, NPOESS and civil and foreign geostationary METSATS to meet DOD objective requirements. Therefore, the DOD requires an architecture to meet objective requirements, preferably two polar and five geostationary systems using the two DMSPs, the two US GOES, the two Meteosat systems, and the Japanese GMS. While other geostationary METSATS are available, namely the Russian, Chinese, and Indian, the systems are extremely unreliable and undesirable. Further, the R & D satellites available are undesirable due to timeliness.

The analysis of National and DOD policy analysis provided the strength of the thesis conclusion providing clear direction on the use civil, international, and commercial space assets. Further, the policy provided commentary of both cost considerations as well as risk mitigation for national security. The policy stated the DOD will coordinate with other departments to foster the integration of satellites and stated the US would conduct international cooperative activities that achieve benefits for the nation.

Further in consideration of risk, MOAs exist between NOAA, through the Departments of Commerce and State and EUMETSAT and JMA. These MOAs provide the DOD the basis for the required oversight and some mechanisms to ensure their requirements continue to be met. Used in conjunction with DOC, which will be used to document agreements with allied nations. To minimize impacts of data reliability, meet threshold and objective requirements differently. Threshold requirements met with US polar orbiting systems. Objective requirements met with Allied partnerships with has safeguards to ensure the continual flow of data and the ability to deny critical data to our adversaries, and provides low-cost alternative to building additional US assets.

US policy addressed METSATS specifically and stated, “the US government will seek to consolidate Earth observation activities to reduce overlaps where cost-effective and consistent with US space goals.”¹ In the case of geostationary METSATS, the cost to develop and deploy US systems to cover overseas regions is too high to justify the benefit received through exploitation of allied METSATS.

In conclusion, DOD threshold spatial requirements are met by DMSP currently and in the future with NPOESS, but the objective goals are not being met due to data refresh rates, especially for real time updates for precision guided munitions and

information operations. However, civil and foreign METSATs are available and capable of meeting DOD's temporal requirements. In order to meet the objective requirements of radiometric, temporal, and spatial accuracy, the DOD requires a weather observational system of METSAT systems, which delivers a constellation of polar-orbiting and geostationary meteorological satellites designed as a space architecture. Existing National and DOD space policy directs the inclusion of civil, foreign and commercial assets in the development of an METSAT space architecture, however there are no commercial METSAT systems currently available. Additionally, DOD requires assurance for data access, continuity and risks mitigation. Fortunately, the DOD and DOC are directed to work concurrently on space architectures per National Policy and the DOC already established initial MOAs with EUMETSAT and JMA, which would complete the potential METSAT architecture. Finally, cost is a major policy consideration for using civil and foreign weather assets vice adding organic DOD assets.

Recommendation

While the DOD historically used allied nation meteorological satellite data, there is a lack of documented requirements on this matter. The DOD requires a system of METSAT systems, which delivers a constellation of polar-orbiting and geostationary METSATs designed as a space architecture. Therefore, the DOD needs to begin coordination within the Services to define the use of METSATs as a technical solution to meet requirements. Further, once concepts are developed, procedures will need to be coordinated with DOC to refine multi-lateral agreements with European and Asian allies.

¹The White House National Science And Technology Council, *Fact Sheet on National Space Policy* (Washington DC: Government Printing Office, 19 September 1996); Internet; accessed on <http://www.c3i.osd.mil/org/c3is/spacepol>

APPENDIX A

RELEVANT OPERATIONAL REQUIREMENTS DOCUMENTS (ORDS) EXAMINED FOR WEATHER SUPPORT REQUIREMENTS

Command	Title	Signed
AFSPC	NAVSTAR Global Positioning System (GPS)	AFSPC/CC 22-Jan-90
AFSPC	Joint Milstar Communications System	USAF/CV 26-Oct-92
AFSPC	Polar MILSATCOM	USAF/CV 11-Jul-95
AFSPC	Defense Support Program (DSP)	USAF/CV 10-Nov-94
AFSPC	Mobile Command and Control (MCCS)	AFSPC/CC 3-Oct-90
AFSPC	Defense Meteorological Support Program	USAF/CV 26-Dec-90
AFSPC	Defense Meteorological Support Program Classified Appendices	USAF/CV 26-Dec-90
AFSPC	Satellite On-board Attack Reporting System	AFSPC/CC 02-Jan-91
AFSPC	Advanced Space-Based Tactical Warning Attack Assessment System	USAF/CV 09-Aug-91
AFSPC	HAVE STARE	HAF/XOR 02-Dec-99
AFSPC	Advanced Entry Control System (AECS)	AFSPC/CC 14-apr-93
AFSPC	Titan IV Space Launch System	USAF/CC 03-Aug-93
AFSPC	Ground-based Electro-Optical Deep Space Surveillance System Modernization	USAF/CV 17-Jun-97
AFSPC	Medium Launch Vehicle III	USAF/CV 03-Aug-93
AFSPC	Theater Missile Defense Space-Based Warning	AFSPC/CC 9-Apr-93
AFSPC	Colorado Command and Control Network	AFSPC/CC 4-Jan-92
AFSPC	Range Standardization and Automation	USAF/CV - 18-Jul-94
AFSPC	Ultrahigh Frequency Satellite Communications	USAF/CV- 24-Jun-96
AFSPC	Evolved Expendable Launch Vehicle	AFSPC/CC 5-Sep-98
AFSPC	Satellite Control	USAF/CV 30-Aug-95
AFSPC	US Nuclear Detonation Detection System	USAF/CV 22-May-99
AFSPC	Very Low Frequency/Low Frequency Capability for the ICBM Launch Control Centers	USAF/CV 16-Jul-96
AFSPC	Space-based Infrared System (SBIRS)	USAF/CV 26-Nov-96
AFSPC	National Polar Orbiting Operational Environmental Satellite System (NPOESS)	VCJCS 28-Mar-96
AFSPC	Advanced Extremely High Frequency (AEHF) Satellite Communication System	AFSPC 19-May-99
HQ USAF	Space Weather Analysis and Forecast System	USAF/CV 01-May-97
AFSPC	Wideband Gapfiller	AFSPC 03-May-00
AFSPC	Worldwide Navigational Positioning System	20-may-97 Draft

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